Uncertainty in the parameterization of land surface schemes: Experience from PILPS

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Extended abstract

The World Climate Research Programme (WCRP) Project for Intercomparison of Land-surface Parameterisation Schemes (PILPS) is a joint activity sponsored by the Global Energy and Water Cycle Experiment (GEWEX) and the Working Group on Numerical Experimentation (WGNE). PILPS has been operational since 1992 with the objective to improve the understanding of Atmospheric Global Climate Models (AGCMs) and Numerical Weather Prediction (NWP) land-surface schemes (LSSs) (Henderson-Sellers *et al.*, 1995).

PILPS consist of five partially concurrent phases. Phase 0 is an on-going documentation stage. Phases 1 and 2 are comprised of a suite of experiments where LSSs are run in an off-line mode and are forced with, and validated against, synthetic (Phase 1) and observational (Phase 2) data. Phase 3 of PILPS is an Atmospheric Model Intercomparison Project (AMIP) Diagnostic Subproject (No. 12) and has been developed to assess the performance of LSSs coupled to their host AGCM. Finally, in Phase 4, several LSSs have been coupled to a single AGCM (Phase 4a) and a single NWP model (Phase 4b) to assess land-atmosphere interactions in numerical simulations. Finally, Phase 4c investigates the development of a generic land surface-atmospheric host model interface.

Phases 1 and 2 have identified very significant scatter in the simulation of all quantities by participating LSSs. PILPS Phase 1 consisted of two main experiments using a single year of GCM-derived forcing data representative of a mid-latitude grassland and tropical forest grid point. Results from Phase 1c (Pitman *et al.*, submitted), showed that values of annually averaged latent and sensible heat fluxes varied significantly between models. In the grassland case, the annually averaged scatter was 34 W m^{-2} (sensible) and 27 W m^{-2} (latent) heat flux. For the tropical forest case the scatter was 79 W m^{-2} (sensible) and 80 W m^{-2} (latent) heat flux. The basic Manabe (1969) bucket scheme was anomalous in both simulations.

In Phase 2 of PILPS, observational data were used to force the LSSs and attempts were made to ensure that, as far as possible, key land-surface characteristics were prescribed in order to permit validation of simulated quantities using observed flux data. To date, Phase 2 has conducted four experiments covering a range of spatial scales and climatology but generally all experiments have been for grassland vegetation. Results from three of the four phases have been reported. Phase 2a (Chen *et al.*, 1997) used validation and forcing data from 1987 for a grassland catchment in Cabauw, the Netherlands. Results from Phase 2a showed that all schemes typically captured the seasonal *patterns* in simulated quantities but that large differences were found between the LSSs for simulated latent and sensible heat fluxes (~30 W m^{-2} annually averaged) and runoff. Seasonally, most schemes lay within the observed error estimates most of the time. Phase 2b used the HAPEX-MOBILHY data from Caumont, France. Again, results showed a wide scatter in simulated quantities. In Phase 2c, 10 years of data from the Red-Arkansas River basin in the United States were used (Wood et al., 1988). This experiment differed from Phase 2a and 2b in that the forcing data were gridded and a routing model was used (Lohmann *et al.*, 1996) to provide modelled catchment streamflow which could be compared to observed streamflow. The LSSs were given the option of calibration and the results show that the calibrated models generally performed better than the uncalibrated models but the mechanisms by which individual LSSs calibrated was not controlled. Results showed that the prediction of runoff in the dry part of the basin was overestimated by most models while over the humid areas the simulations tended to be more accurate (Lohmann *et al.*, 1998). All schemes under-predicted evapotranspiration in summer and over-predicted it in winter. Observations suggest that evapotranspiration during the summer exceeds precipitation, which suggests a need for accurate parameterisations of soil and rooting depth as it is these determine how much water can be stored and used for dry-season evapotranspiration. Finally, Phase 2d was designed to explore the treatment of snow and frozen soil processes using a set of meteorological and hydrological observations spanning 18-years from a grassland catchment at Valdai, Russia (see Vinnikov *et al.,* 1996; Schlosser *et al.,* 1997). Schlosser *et al.* (1998) summarize the models' performance and sensitivities and shows that, given uncertainty in the observed data, the models' performance are within observational error and no model produces a simulation which can be demonstrated as erroneous.

Since these results are all off-line, their implications for coupled simulations are unclear. However, initial results from Phase 4a and 4b provide additional evidence of the impact of different land surface schemes on a host model. For example, Timbal and Henderson-Sellers (1998) used the Australian Bureau of Meteorology's Limited Area Prediction System (LAPS) coupled to four LSSs and performed a suite of 48-h simulations over the Australian region at 4°x 4° horizontal resolution. To simplify the experiments, the Australian continent was covered in an homogeneous grassland, growing in a medium coarse soil type. Preliminary results suggest that the choice of LSS does affect the simulated meteorology, and more interestingly, the choice of complex scheme also affects the simulated meteorology indicating that the differences between complex schemes (seen in offline simulations) are large enough to impact on a host model. There are problems with guaranteeing that the coupling of the LSSs to LAPS (or any other host model) is effectively identical since coupling a different scheme into a host model sometimes requires major code restructuring. Polcher et al. (1998) are developing a generic interface in an attempt to overcome this problem. However, even if a generic interface is developed, the difficulty in specifying parameters to a suite of LSS all of which have the same effective values will remain a problem.
While PILPS's intercomparison of simulations from a large number of land surface models has allowed an assessment of uncertainty within the land surface modelling community, other methods are required to explore the reasons behind the simulation differences. With so many potential sources of simulation difference, some method is required to simplify the situation being studied. To this end, Koster and Milly (1997) extracted simple relationships from the monthly hydrology of each model's PILPS 1c simulations and analysed those relationships in place of the actual simulations. They showed that the basic characteristics of each model's monthly hydrological simulation could be reconstructed from the simple relationships. Using forcing from Phases 1c, 2a and 2b of PILPS and interpreting the results in terms of the PILPS experiments, Desborough (1997, 1998) investigated how inter-model variations in specific aspects of land surface parameterisation affect model behaviour by isolating those differences within a single modelling framework. Desborough (1997) focussed on evaporation stress parameterisation and particularly on transpiration moisture stress parameterisation.

Desborough (1998, submitted) examined how general aspects of surface energy balance complexity affect model behavior. The anomalous behavior of the Manabe (1969) bucket model in PILPS is shown to be caused by a combination of its evaporation stress and aerodynamic parameterisations with both aspects required to fully explain the behavior of the model. It is also shown that while accumatively adding complexity to the surface energy balance parameterisation of a simple bucket does affect the model's behavior, these impacts are not significant with respect to uncertainty range defined by PILPS scatter.

PILPS has shown that there is a large amount of uncertainty in the parameterisation of land surface processes and that although adding complexity to a model does *change* its simulation, it cannot be shown to *improve* the simulation. To a large degree, this is due to the size of the scatter in control experiments. If this was reduced through improved understanding, it might be that adding in a physical process to a LSS (interception, temporally varying canopy resistance etc) could be seen to generally improve the predictive skill of a LSS. However, at present, PILPS has not provided any evidence that complexity leads to a better model. Overall, at the present time, we believe that the choice of which LSS to use in a numerical model is philosophical. From PILPS results, it is not possible to argue that complexity equals better, and yet in principal, more physical processes might be expected to enable a LSS to simulate important observed processes or feedbacks. Similarly, it might be argued that simplicity means important processes are omitted and that this is a weakness. However, identified problems are smaller than the underlying uncertainty amongst complex schemes and it may well be that this should encourage the application of Occam's razor.

This paper will briefly review PILPS and key results. We will then focus on the methodology used to try to understand the causes of the differences, results generated through this methodology and the implications of these results to the design of LSSs.

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